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TNT AS A BLASTING EXPLOSIVE

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INTRODUCTION.

THIS report presents the results of an investigation conducted by the United States Bureau of Mines to discover the safest and best ways of utilizing TNT for industrial blasting purposes. It describes the physical and chemical properties of the different grades of the explosives, gives precautions to be observed in handling, packing, preparation of cartridges, and charging, presents the results of field tests in blasting stumps, rocks, and other work, and compares the results with those obtained from dynamite.

The investigations reported herein were undertaken and this paper has been prepared solely to aid in the salvage of the surplus TNT accumulated for war uses and released by the declaration of the armistice. No funds were available nor have any been appropriated with which to defray the expense of converting this TNT into any other form or to prepare any explosive mixture from it. The sole problem was to find appropriate uses for the TNT in existing needs and to show that it could be efficiently used without change in carrying out essential civil projects.

It is not intended to promote the use of TNT as an industrial explosive. On the contrary, the authors believe that TNT is unlikely to be generally used, principally because of its cost. The clouds of smoke given off by TNT on explosion show that we are not obtaining from it its highest efficiency. It can be improved by mixing the TNT in proper proportions with sodium nitrate or ammonium nitrate or some other cheap oxidizing agent which will consume the excess combustible matter in the TNT. By such admixture not only will the energy resident in the TNT be utilized to a larger extent, but the cost of the resulting explosive should be much less than that of TNT. It may be desirable to add other material with which to waterproof this product. But these are problems which should be treated elsewhere.

[1] While this circular was prepared by representatives of the Bureau of Mines of the United States Department of the Interior, it is published by the United States Department of Agriculture for the Bureau of Public Roads because of the importance of the subject-matter at the present time in connection with the use of TNT in the construction of Federal Aid and Forest Reserve roads.

NOMENCLATURE.

TNT is an explosive that is obtained by acting upon toluene with nitric acid in the presence of sulphuric acid. Toluene is a liquid substance which is produced from soft coal in the process of making coke, coal gas, and coal tar, and it is recovered for use from both the gas and the tar. It is also made in other ways. TNT is an abbreviation of the chemical name trinitrotoluene. The existence of six different trinitrotoluenes is recognized. The material which has been so largely used as an explosive in recent warfare consists wholly or largely of the α or symmetric variety of trinitrotoluene, and this has come to be specifically designated by the name TNT.

HISTORY.

TNT has been known to chemists since 1863. It had been adopted as a military service explosive by 1902, but it did not become widely known until the Great War, when it came to be extensively used in bursting charges for high explosive shell, depth bombs, mines, torpedoes, and other devices, and in demolitions where very violent detonation effects were sought to be produced with the largest measure of safety from these effects to the users. It was also used in admixture with other substances to produce other military explosives, such as amatol and sodatol.

SAFETY.

Because of the devastating effects produced by the explosion of these devices charged with TNT and because of the many disastrous accidents that have occurred during the manufacture and transportation of large quantities of TNT in the hurry incident to the war, many have been led to conclude that TNT is an especially dangerous explosive; on the contrary, it really possesses characteristics which render it less dangerous than many explosives generally used in our industries. Thus it has been found more difficult to explode with certainty than nitroglycerin, dynamite, or guncotton. In fact, TNT was considered so safe that in 1910 the British Government, on advice of its explosives experts, issued an order in council exempting it, when properly packed, from certain provisions of the explosives regulations affecting its manufacture, storage, conveyance, and importation. This order has since been rescinded, and it may be proper to say in this connection that all substances possessing explosive properties should be treated with special care and surrounded by safeguards.

INDUSTRIAL USE.

With the cessation of hostilities the Government found itself with such large supplies of TNT on hand that it was deemed unwise to keep it all in storage awaiting future military use, and it was proposed

to dispose of many million pounds for industrial use. Nitrotoluenes in admixture with other substances have been used as industrial explosives to a certain extent for more than a decade, but TNT, as such, has been used in a tentative way only for industrial blasting. It is not surprising, therefore, that objections should have been made to its suggested use as an industrial blasting agent and that doubts should have been expressed as to its effectiveness. The purposes of this paper are to show how TNT may be safely and efficiently used in industrial blasting operations by those skilled in blasting, and to correct many erroneous or misleading statements which have been circulated as to the properties of TNT, by giving the results of careful experiments and observations, many of which have recently been made at the Bureau of Mines explosives experiment station near Pittsburgh, Pa., and in field tests made under the auspices of the college of agriculture of the University of Wisconsin.

PUBLIC USE.

When it had been demonstrated at the Bureau of Mines experiment station that TNT possessed value as a blasting explosive and could be used with a reasonable degree of safety, allotments from the surplus stock of the War Department assigned to the Department of the Interior were made to the Reclamation Service, National Parks Service, Board of Indian Commissioners, Alaskan Engineering Commission, and Bureau of Public Roads for use on Government projects. It has now been used to the extent of several million pounds for all the numerous purposes of these engineering agencies and in all weathers and under all natural temperatures encountered from New Mexico to Alaska. A large number of reports have been received from these operations and all sustain the conclusions drawn from the experimental work.

GENERAL CHARACTERISTICS.

Chemically pure TNT is a pale yellow, crystalline substance which acquires a deep yellow to brown color on exposure to light. It melts at about 80.5° C. (177.9° F.) and when in the molten state is cast into shells or run into cold water which chills it and causes it to assume the form of granules or of pebbles or pellets. TNT may, therefore, appear in granulated crystalline form, in pebbled or pelleted form, or in blocks or other cast forms. That offered by the Department of the Interior for use in blasting is in the granulated crystalline form. Naturally, as produced on a large scale, TNT is not chemically pure, though the admixed substances are principally other nitrotoluenes which do not materially affect the explosive quality of the product, though they do change its appearance and other physical characteristics. The TNT secured by the War Department and allotted to the Department of the Interior for industrial use is of

three grades, as follows: Grade I, having a setting point (S. P.) of 80° C. (176° C.); Grade II, S. P. 79.5° F. (175.1° F.) and Grade III, S. P. 76° C. (168.8° F.). The setting point of the molten TNT is employed by the Ordnance Corps, United States Army, as the criterion of purity, because it is more readily observed with accuracy than is the melting point of the solid. Grade I appears as a dry, granular, crystalline powder, slightly yellow in color, and so fine that it will pass through a 30-mesh sieve; because of its dryness it readily gives off dust. Grade II is a granular, crystalline powder resembling light brown sugar, with a reddish tinge, and so fine that it will pass through a 12-mesh sieve; it is less dry and therefore less free-running and dusty than No. 1. Grade III is a dry crystalline, granular powder having a pale sulphur-yellow color, and is so fine that it will pass through a 12-mesh sieve. It is not dusty, has the consistency of brown sugar, looks as if it were slightly moist or greasy, shows a tendency to cake, and is less "free running" than No. II.

SOLUBILITY AND HYGROSCOPICITY.

TNT is almost insoluble in water. According to Marshall, water at 15° C. (59° F.) dissolves 0.021 per cent of it, and at 100° C. (212 ° F.), 0.164 per cent. In other words, 100,000 parts of water at 15° C. dissolves 21 parts of TNT, and at 100° C., 164 parts. The solubility of the different grades mentioned above is of the same order. In fact, the lower grades, and especially Grade III, have a greasy feel and appearance and are, to a degree, water repellant. The proved low solubility of TNT shows that it can not be deliquescent or more than slightly, if at all, hygroscopic. Investigation at the Bureau of Mines explosives experiment station has shown that it absorbs moisture when exposed to the atmosphere to about the same extent as powdered glass. This is for all practical purposes an entirely negligible quantity.

PACKAGES.

Military TNT, as offered for use in industrial operations, is packed in the granular crystalline form, in boxes made of white pine five-eighths inch thick. The boxes are of lock-cornered construction and lined with paraffined paper. Most of the boxes of TNT received at the explosives experiment station of the bureau were 22⅜ by 15¼ by 13 inches outside dimensions, and occupied a volume of 4,436 cubic inches (2.57 cubic feet). The boxes contained 100 pounds of TNT and their gross weight averaged 113 pounds. It is possible that the boxes supplied by other manufacturers differ in dimensions and weight from these. The tops and bottoms are fastened on with nails. In opening the boxes, if force is necessary, the covers should be pried off with wooden wedges. Grades II and

III tend to cake during storage, and the lumps must be broken up to render the explosive "free running" so that it may be made into cartridges or loaded directly into bore holes. The lumps may be so broken by pressing them with a wooden paddle or striking them light blows with a wooden mallet on a wooden surface.

POISONING.

TNT has a faint smell and a bitter taste. It produces brown stains on the skin which are difficult to remove. It is toxic and may poison if inhaled as dust, if taken into the mouth, or if absorbed through the skin but, unlike nitroglycerin, which produces severe headaches if even a minute quantity touches the skin, rather long contact with TNT is required before its toxic effects become serious, and then it rarely, if ever, produces headache. Nevertheless, those engaged in handling it should avoid getting it into the nose and mouth, and should clean their hands thoroughly before eating.

DETONATION.

TNT is more difficult to detonate with certainty than nitroglycerin, dynamite, or the explosives ordinarily used in engineering operations, in mining, and in quarrying. TNT charges require a No. 8 detonator (blasting cap) or electric detonator, whereas dynamite and the other high explosives ordinarily used in industrial operations require but a No. 6 detonator. Objection has been raised to the use of TNT on the ground of the increased cost of the stronger detonator. From inspection of current price lists it appears that a No. 8 detonator costs nine-tenths of a cent more than a No. 6, and that No. 8 electric detonators cost 1.7 cents more than No. 6 electric detonators do.

SENSITIVENESS.

As shown by tests with the pendulum friction device [1] all three grades of TNT are less sensitive to friction than "40 per cent" straight dynamite, gelatin dynamite, or picric acid, and as shown by tests with the large impact machine all are less sensitive to percussion than "40 per cent" straight dynamite, ammonia dynamite, and nitrostarch powders. TNT may burn if set on fire, and this burning may change to detonation. Hence TNT must be protected from fire, and causes of fire, such as sparks, flame, heated bodies, friction, percussion, and the like, as all explosives should be at all times.

In Wisconsin it was found that TNT was not detonated by bullets from a high-powered rifle. In test with a 35-caliber rifle no explosion of TNT occurred when the cartridge was shot to pieces with bullets.

[1] For a description of this device and of the large impact machine, see Bulletin 66, "Tests of Permissible Explosives," by Clarence Hall and S. P. Howell, Bureau of Mines, 1913, pp. 15–17.

Marshall,[1] using the "rifle bullet test," which consists in packing about 1 pound of the explosive to be tested in a $3\frac{1}{2}$-inch cube box of cardboard or tin and firing into it from a distance of 30 yards with a standard U. S. Army rifle (New Springfield), found that no detonations were obtained when the TNT was packed in cardboard boxes, but that when it was packed in tin boxes the first and second hit in every case set fire to the TNT, and the third hit gave a detonation.

EXPLOSION BY INFLUENCE.

In experiments made at Madison and Rice Lake, Wis., cartridges were cut in half and the halves rolled up in such a manner that the two halves were held at a measured distance apart. (See fig. 1) A detonator was placed in the outer end of one of the halves and the system fired. It is evident that by varying either the distance

FIG. 1.—Explosion by influence.

between the halves of the cartridge or the strength of the detonators, the sensitiveness of the explosives and the efficiency of the detonators may be measured. In these tests, at temperatures of 70° F. to 74° F., the No. 6 detonator failed to detonate the second half at a distance of 6 inches, but sometimes did detonate it at 5 inches. The No. 8 detonator always detonated the second half at 5 inches and sometimes at 6 inches. In the same test, using "20 per cent" ammonia dynamite instead of TNT, the No. 6 detonated both halves of this dynamite at a distance of 8 to 9 inches.

GASEOUS PRODUCTS OF DETONATION.

When TNT is detonated a considerable amount of finely divided carbon is set free and various gases are formed; the kinds of gases and the quantity of each depend upon the kind and amount of detonant used, the presence or absence of wrappers and their character, the presence or absence of air, and other variables. Hence it is not surprising that many different statements as to the gaseous products of detonation of TNT should appear in the literature. In all of the compositions given, carbon monoxide (CO) and hydrogen (H)

[1] Journal of Industrial and Engineering Chemistry, Vol. 12, p. 359, April, 1920.

are present in considerable quantities, usually associated with methane (CH_4), and sometimes other hydrocarbons. All of these gases are inflammable and combustible and form explosive mixtures with air. Carbon monoxide is also extremely poisonous. Hence TNT is unsafe to use in close places, such as underground workings and particularly coal mines. These results emphasize the importance of remaining away from the face of any blast after an explosion of TNT until assured that the gases produced have been blown away or diffused from the interstices of the débris. The safe waiting time will, of course, vary with the quantity of explosive fired, the location, such as a pocket, valley, or plain, and the atmospheric conditions, particularly the force and direction of the wind. These precautions are such as should be taken with all explosives.

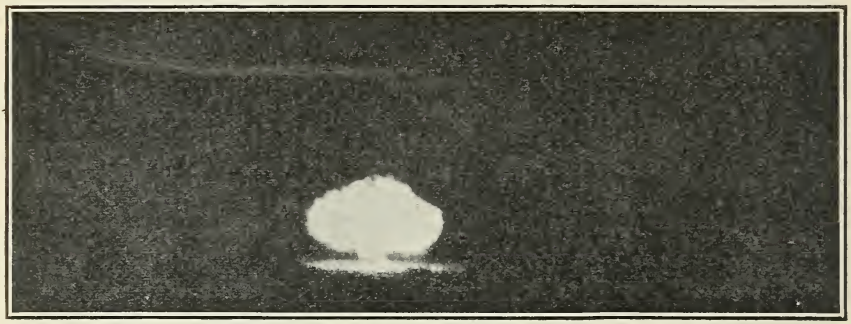

FIG. 2.—Flame from detonating TNT.

When completely detonated, TNT yields a black smoke and a brilliant flame. (Fig. 2.) When incompletely detonated its smoke is gray.

RELATIVE EFFICIENCY.

In determining the relative efficiencies of explosives in use, the Bureau of Mines has long employed the "unit deflective charge," and the "rate of detonation" as criteria. The unit deflective charge is ascertained by exploding a known weight of the explosive in the ballistic pendulum and this term, "unit deflective charge," is defined as "that weight of an explosive which will swing the ballistic pendulum the same distance as one-half pound of 40 per cent straight nitroglycerin dynamite." It appears that explosives of which the unit deflective charge is smaller have the greater propulsive capacity; hence, the unit deflective charge is considered a measure of the ability of an explosive to dislodge and bring down material in which it is exploded. For a more detailed description of the apparatus and method the reader is referred to Bulletin 66 [1] and Bulletin 15.[2]

[1] Hall, Clarence, and Howell, S. P., Tests of permissible explosives, Bul. 66, Bureau of Mines, 1913, pp. 11–12.

[2] Hall, Clarence, and others, Investigations of explosives used in coal mines, Bul. 15, Bureau of Mines, 1912, pp. 79–82.

UNIT DEFLECTIVE CHARGE.

The unit deflective charge, in grams, of "40 per cent" dynamite and of Grades I, II, and III of TNT, with their corresponding propulsive capacity expressed in percentages of the propulsive value of 40 per cent dynamite, are given in the following tabulation:

TABLE 1.—*Unit deflective charge of four explosives.*

Item.	Dynamite, 40 per cent strength.	TNT		
		Grade I.	Grade II.	Grade III.
Unit deflective charge.....grams..	227	201	199	209
Propulsive capacity.....per cent..	100	113	114	109

From the above it will be seen that each grade of TNT is stronger when so measured than 40 per cent straight nitroglycerin dynamite.

RATE OF DETONATION.

The method of determining the rate of detonation is to charge the explosive in a file 1¼ inches in diameter and 42 inches long at normal density (that is, no unusual effort is made to develop high density) and to fire the charge with a No. 8 electric detonator.

The "rate of detonation" is considered a measure of the ability of an explosive to disrupt and shatter material in which it is exploded. The results of such tests are given in the following tabulation:

TABLE 2.—*Rate of detonation of four explosives.*

Item.	Dynamite, 40 per cent strength.	TNT		
		Grade I.	Grade II.	Grade III.
Apparent specific gravity.....	1.24	0.91	0.88	0.86
Rate of detonation.....meters per second..	4,772	4,747	4,852	4,482
Rate of detonation.....per cent..	100	99	102	94

It should be carefully noted that the comparisons made in the unit deflective charge table are by weight and in the rate of detonation table by volume.

As an outcome of the Wisconsin investigation, in the course of which data were obtained for a large number of stumps blasted, it was determined that the necessary charges per square inch of stump cross-section were 0.055 ounce of "20 per cent" ammonia dynamite, 0.0387 ounce of TNT, when using No. 8 cap, and 0.0445 ounce of TNT when using a No. 6 cap. This indicates a slight advantage for the No. 8 cap, and it was believed by the operators that in the use of the explosive a stronger effect was noticeable with the larger

cap. Hence in determining a load it seems desirable to allow about three fourths as much TNT as would be required of the ordinary dynamites.

In ditching about the same results were obtained with a 5½-ounce cartridge of TNT as were obtained with an 8-ounce cartridge of 20 per cent ammonia dynamite. With one cartridge of TNT in a hole, the holes placed 18 inches apart and driven 24 inches deep, and the charge detonated with No. 6 electric caps, a ditch 54 inches wide and about 20 inches deep was made. (Fig. 3.) Approximately the same size ditch was made with 8-ounce cartridges of 20 per cent ammonia dynamite placed in the same way.

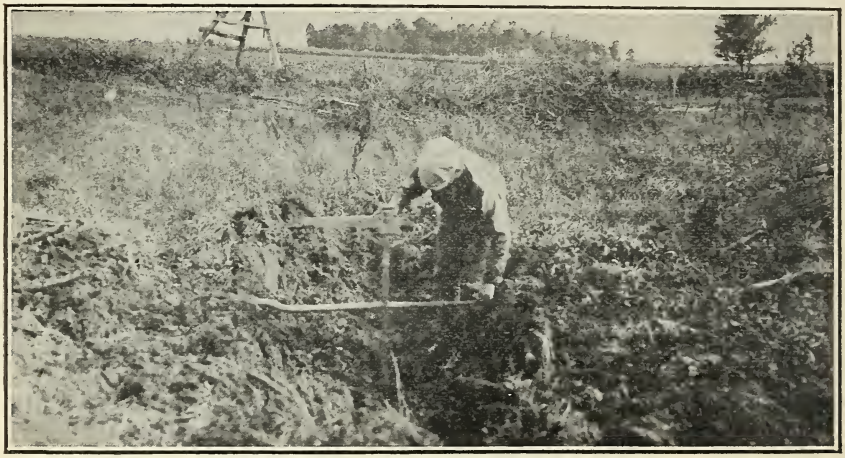

FIG. 3.—Section of ditch made with TNT.

In rock work very satisfactory results were obtained by using quantities of TNT that were about 75 per cent of those of the 20 per cent ammonia dynamite usually used.

PACKING IN CARTRIDGES.

When either of the three grades of TNT is packed in cartridge cases or in bore holes under ordinary tamping pressures, the apparent specific gravity of the charges varies from 0.81 to 0.95, whereas when 40 per cent straight dynamite is so packed, the apparent specific gravity of the charges ranges from 1.15 to 1.34. Evidently, for equal weights the TNT cartridges will be more bulky than the dynamite cartridges. As a consequence, larger bore holes must be used for TNT charges than for dynamite charges of equal weight. This presents an advantage for the dynamite over the TNT, but, on the other hand, observation has shown that as the apparent gravity of the TNT approaches the lower limit given above, the resistance of the explosive to wetting, when the cartridges

are immersed in water, increases. Hence, it is recommended that except in assuredly dry holes, or in big blasts, where full boxes of the explosive may be fired in chambers, the TNT be packed for use in cartridges and that, as Grade III is the most water resistant of them all, this grade be packed under low pressure and reserved for use in especially wet work. To particularly distinguish the cartridges of Grade III, the wrappers may be of a specially chosen color, or better yet, they may be packed in paraffin-coated wrappers; after the charge has been packed in these wrappers and the ends folded in, the ends should be redipped in the molten paraffin to seal them completely. For emergency use, newspaper made up into cylinders of the desired dimensions by rolling about a pick handle or other convenient tool may be employed for wrappers, but where considerable quantities are to be packed, the better plan is to pack the explosive in standard manila wrappers, made by means of a cartridge machine.

Grade I is so dry that it always gives rise to considerable dust when it is being handled or packed and Grade II is often dusty. As this dust is unwholesome when inhaled and when deposited on the skin, its formation should be avoided as far as possible. To do this it is proposed to moisten such TNT with 4 per cent of its weight of water. Tests at the Pittsburgh experiment station show that this quantity of water completely lays the dust and facilitates packing and does not unfavorably affect the detonation of the TNT by a No. 8 detonator.

PRECAUTIONS TO BE TAKEN IN PACKING.

It is only in large-scale operations of crushing and repacking TNT into cartridges that there is much likelihood of anyone becoming poisoned, for, as a rule, continued contact with the explosive for some time is required to produce this result. In handling TNT the following rules should be observed:

(1) Only persons in good health should be employed.
(2) Special clothing should be provided, to be used only during working hours. Gauntleted gloves may be worn, but this is not necessary.
(3) The hands and face should be washed before meals and before leaving the factory.
(4) Care should be taken that none of the TNT comes in contact with the mucous membrane, such as that of the mouth, nose, eyes, etc. Workers should, therefore, be cautioned against touching these parts with their hands, or taking anything into the mouth while handling the explosive.

Cases of TNT poisoning, which have occurred in considerable numbers in the factories operated under war conditions, appear to have resulted from neglecting to observe the foregoing rules.

Usually the first evidence of poisoning is the appearance of a rash on the hands, neck, or face. When this occurs, the case should receive prompt medical attention, and it is desirable to transfer the person to other work. In this way a worker who is easily susceptible to TNT poisoning will not be exposed further to danger. In factories where the opportunities for TNT poisoning are great, the effects usually do not appear until after five weeks of work.

In Wisconsin four men were selected to engage in all the phases of the preparation and use of TNT in the field test. These men handled the bulk TNT prepared the cartridges, and used them in the field, on stump, rock, and ditch work. They worked in the field, breathed the fumes and smoke, and in every way made efforts to determine any poisonous effects. After nearly four weeks' work with the explosive no effects whatever were noticed. The fumes, though heavy, disappeared quickly, and the fact that the work was done in open air seemed to remove all danger of poisoning. Where a No. 6 detonator was used incomplete detonation occurred, and the fumes from the hole were so strong that they were naturally avoided, as far as possible, while work was continued.

CHARGING BORE HOLES.

TNT should be charged into bore holes, primed, tamped, and stemmed in the manner customarily followed in the use of high explosives in blasting, special care being taken in charging wet holes not to tear or break the cartridge case or wrapper while loading the cartridge into the hole and tamping it. It may be used in chambering holes, for subsequent charging with black blasting powder, just as dynamite is used. When TNT shots are fired, if the detonation is complete, there will be produced large volumes of dense black smoke.

PRACTICAL DEMONSTRATIONS IN THE FIELD.

TESTS AT THE BUREAU OF MINES EXPLOSIVES STATIONS.

The practical value of TNT, Grade III, for general blasting purposes has been demonstrated by a number of field tests, such as adobe shots on bowlders and concrete piers, blasting out oak stumps, splitting oak logs, and shooting under water. In all the tests described herein the TNT was loaded in extemporized wrappers, made from newspapers, and detonated by means of a No. 8 electric detonator. A brief description of these tests, made at the bureau's explosives experiment station near Pittsburgh, Pa., by A. B. Coates, J. E. Tiffany, and W. J. Montgomery, is as follows:

Test 1.—Adobe Shot.

A 1½-pound charge of the explosive was mud-capped with wet clay and fired on a sandstone bowlder 6 feet long, 3 feet wide, and 1½ feet thick. The largest piece obtained was 2 by 2 feet by 1 foot. Forty per cent of the bowlder was broken into fragments 2 inches or less in size.

TEST 2.—ADOBE SHOT.

In removing two concrete piers 10 feet long, 7 feet high, 1½ feet thick at the top and 3½ feet thick at the bottom, an opportunity was given to compare TNT directly with "40 per cent" straight nitroglycerin dynamite. All shots fired were abode shots mud-capped with moistened clay. In six blasts, using a total weight of 10.7 pounds of the TNT, 159.5 cubic feet of concrete were removed, or 14.9 cubic feet per pound of TNT, whereas in five blasts, using a total weight of 9.6 pounds of dynamite, 135 cubic feet were removed, or 14.1 cubic feet per pound of 40 per cent dynamite.

FIG. 4.—The blast. A 3-foot oak stump shot with 6 pounds of Grade III, TNT.

TEST 3.—STUMP BLASTING.

A solid oak stump 3 feet in diameter, rooted in clay, was removed by the use of six 1½-pound charges of TNT, one charge being inserted under each lateral root and one under the tap root. The stump was broken into two pieces of approximately equal size, which were thrown 35 and 65 feet respectively from their original position. (Fig. 4.) A crater 12 feet in diameter and 4 feet deep was formed. This shot was evidently overloaded.

TEST 4.—STUMP BLASTING.

An oak stump 3 feet in diameter, rooted in clay and sandstone fragments, was removed by the use of eight ¾-pound charges, six being placed under the lateral roots and two under the center. The stump was broken into 4 pieces, 2 large and 2 small. The large pieces were overturned at the edge of the crater, one small piece remained loose in the ground and the other was thrown about 75 feet. (Figs. 6 and 7 show the stump before and after the blast.) In connection with this test, it is important to call attention to the fact that the charges were loaded in wet holes for a period of 1½ hours.

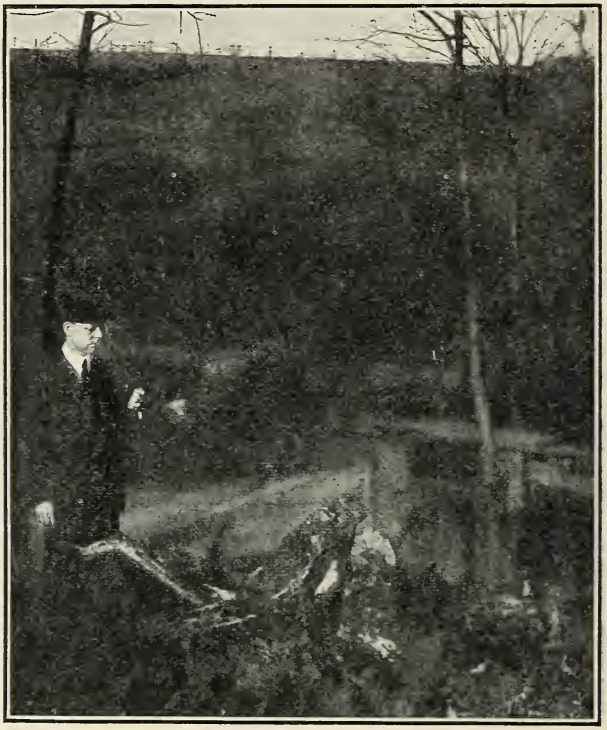

FIG. 5.—Result of blast on 18-inch oak stump shot with 2 pounds of Grade III, TNT.

TEST 5.—STUMP BLASTING.

An oak stump 18 inches in diameter, rooted in clay, was removed by a single 2-pound charge of Grade III TNT, placed under the center of the stump. The stump was broken into two pieces and overturned at the edge of the crater, as shown in figure 5.

TEST 6.—STUMP BLASTING.

A solid oak stump 3 feet in diameter, rooted in clay, was removed by four 1¾-pound charges placed under the lateral roots. The stump

was split into 3 large pieces, which were lifted about 10 feet in the air and fell back into the crater. (Fig. 8.)

TEST 7.—LOG SPLITTING.

A solid oak log 6 feet long and 39 inches in diameter was split into two separate pieces of practically the same size by 4 ounces of Grade III TNT, loaded in a 2-inch hole located midway between the ends and about 2 inches beyond the center of the log.

TEST 8.—LOG SPLITTING.

A solid oak log, 6 feet long, 44 inches in diameter at one end and 40 inches at the other, was split into two pieces of practically the same size by 5 ounces of Grade III TNT loaded as in test 7.

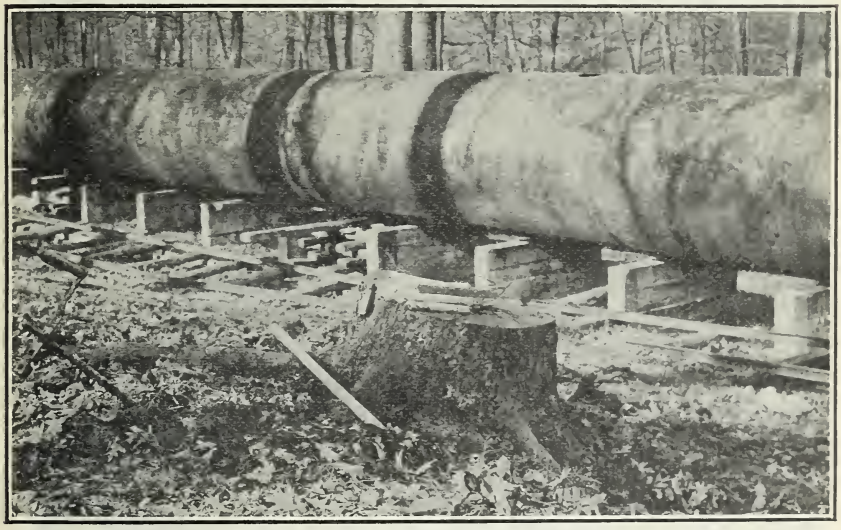

FIG. 6.—Three-foot oak stump before shot, showing charge—6 pounds of Grade III, TNT.

TEST 9.—WET BORE HOLES.

As the ability to use an explosive under water in very wet bore holes is of great importance, the following test was carried out:

A bore hole 1½ inches in diameter and 42 inches in depth was drilled vertically in the floor of a coal mine, through coal, limestone, and fire clay. The top of the bore hole was 4 inches under water. As the maximum effect was sought, the bore hole was overloaded with 2 pounds of Grade III TNT, the explosive being pressed in sufficiently hard to break up the cartridge. No tamping was used. After a wait of 15 minutes, the charge was fired. A crater 4 feet in diameter and 42 inches deep was formed and considerable other material about the crater was so loosened as to be removed by a pick.

FIG. 7.—Result of blast on 3-foot oak stump shot with 6 pounds of Grade III, TNT.

FIG. 8.—Crater formed by 7 pounds of Grade III, TNT, in shooting 3-foot oak stump

Conclusions as to Results of Tests.

(1) Grade III TNT can be successfully used for adobe shots of bowlders, for removing stumps, and for splitting logs.

(2) Grade III TNT has shown that it will give results the equal of 40 per cent straight nitroglycerin dynamite.

(3) Grade III TNT detonates completely with a No. 8 electric detonator.

(4) The appearance of black smoke is not to be taken as an evidence of incomplete detonation.

(5) Grade III TNT detonates completely under water.

(6) Grade III TNT detonates completely after moderate immersion in wet holes.

Fig. 9.—Pine stumps blown with TNT, using No. 6 detonator. Before.

EXPERIMENTS BY COLLEGE OF AGRICULTURE, WISCONSIN.

Extensive stump-blasting operations have been carried on under the supervision of Mr. Swenehart, of the college of agriculture of the University of Wisconsin, in which careful records have been made of the character, form, and dimensions of each stump, the soil in which it grew, the character, quantity, and disposition of the charge, and the effect of the blast. Stumps of various species have been blown, the larger number pine, while the soils varied from silt loam through clay to sand. Similar, though fewer, trials were made of the use of TNT in driving ditches and breaking rock.

In these tests both No. 6 and No. 8 detonators were used. The pine stumps shown in figure 9, were blown with the use of a No. 6 detonator; the results of the blast are shown in figure 10. Figures 11 and 12 show stumps before and after blasting, using a No. 8 detonator.

FIG. 10.—Pine stumps blown with TNT, using No. 6 detonator. After.

FIG. 11.—Blasting pine stumps with TNT, using No. 8 detonator. Before.

FIG. 12.—Blasting pine stumps with TNT, using No. 8 detonator. After.

CONCLUSIONS AS TO RESULTS OF THE TESTS.

As a result of these tests the following conclusions have been reached by the Wisconsin officials.

(1) TNT can be safely cartridged and handled for land clearing.

(2) TNT is a usable explosive for land clearing, and its desirability will depend on the cost to the user.

(3) Complete detonation and best results with the use of TNT require the use of No. 8 detonators. The No. 6 detonator usually detonated the TNT, but better results were obtained with the No. 8. The results will amply justify the small extra cost of the No. 8 detonator, which is 0.9 cents ($0.009) per detonator.

(4) Moisture which is encountered in ordinary land clearing operations does not materially affect the work of TNT.

(5) Ordinary variations in temperature do not materially affect the work of TNT.

(6) The health of the users in open-air work is not noticeably affected.

(7) The amount of TNT required is about 75 per cent of the necessary charge at "20 per cent" ammonia dynamite.

(8) On account of the smaller quantities used, definite sizes of cartridges should be made. There may be considerable danger from overloads if the material is not properly cartridged.

TRAUZL BLOCK TESTS.

The results of the tests of TNT and other explosives when fired in cavities in lead blocks by the Trauzl method[1] as practiced by the Bureau of Mines, are given in the following tabulation in terms of the increase in volume of the cavities in each test, and these results are compared with one another by taking 40 per cent "straight" dynamite as standard.

TABLE 3.—*Lead block expansion of eight explosives.*

Explosive.	Expansion.	
	c. c.	*Per cent.*
Blasting gelatin	400	149.8
60 per cent "straight" dynamite	321	120.2
Granulated TNT	302	113.1
50 per cent "straight" dynamite	281	105.2
40 per cent "straight" dynamite	267	100.0
40 per cent ammonia dynamite	202	75.7
40 per cent gelatin dynamite	195	73.0
Black blasting powder	28	10.5

[1] For description see Hall, Clarence, and Howell, S. P., Tests of permissible explosives, Bul. 66, Bureau of Mines, 1913, p. 7.

WATER-RESISTING PROPERTIES.

EXPERIMENTS AT BUREAU OF MINES EXPLOSIVES STATION.

As some blasting must be done in damp or very wet holes, it is desirable to know the water-resisting properties of the different grades of TNT as compared with such well-known commercial explosives as 40 per cent "straight" nitroglycerin dynamite and 40 per cent strength ammonia dynamite. Therefore, $1\frac{1}{4}$ by 8-inch cartridges of Grade I, Grade II, and Grade III TNT and the two dynamites were submerged in thoroughly wet sand in pans at room temperature for definite periods of time, after which an attempt was made to detonate each cartridge when confined in sand in a bore hole. No. 6 electric detonators were used with the TNT, and the dynamites. If complete detonation occurred in each of three trials, the explosive was considered as having sufficiently resisted the water.

The dynamites were tested as received and also after the wrapper was punctured with 16 small holes to simulate a broken cartridge. The ammonia dynamite had the appearance of being redipped by immersion in paraffin, while it appeared that the "straight" dynamite had the machine-crimped end (the one last closed) sprayed with paraffin. Each grade of TNT was tested in three types of cartridges—newspaper, paraffined paper with one end redipped, and paraffined paper with both ends redipped. The TNT cartridges were tested with and without the puncturing and packed both hard and easy into the cartridges. The tests were made at the explosives experiment station of the Bureau of Mines by Edmund Stein.

The apparent specific gravity of the different grades of TNT when packed hard and packed easy and of the dynamites as received are shown in Table 4.

TABLE 4.—*Apparent specific gravity of five explosives.*

Explosive.	Apparent specific gravity.		
	As received.	Packed hard.	Packed easy.
40 per cent "straight" nitroglycerin dynamite	1.29		
40 per cent ammonia dynamite	1.53		
TNT:			
Grade I		0.89 to 0.93	0.85 to 0.90
Grade II		.87 to .92	.81 to .86
Grade III		.89 to .98	.81 to .86

For convenience, the following abbreviations are used in Tables 5, 6, and 7:

c, the cartridge detonated completely.
p, the cartridge detonated partially.
n, the cartridge did not detonate.
N, the cartridge was made with a newspaper wrapper.
P, one end of the paraffined paper cartridge was redipped.
PP, both ends of the paraffined paper cartridge were redipped.
H, cartridges were packed hard.
E, cartridges were packed easy.
A, cartridges were not punctured.
B, cartridges were punctured.

TABLE 5.—*Hours of immersion resisted by two dynamites.*

Hours.	40 per cent ammonia dynamite.		40 per cent "straight" dynamite.	
	A.	B.	A.	B.
2	.....	c	.....	c
4	.....	c	.....	c
8	.....	.....	.....	.....
16	.....	c	.....	c
24	.....	ccc	ccc	cc
48	ccc	pcp	ncc	ccc
72	ppp	cn	pnp	cp

Both of these dynamites will detonate completely after 24 hours immersion and under certain conditions after 48 hours immersion.

TABLE 6.—*Hours of immersion resisted by TNT.*

GRADE I.

Hours.	N H A.	N E A.	N H B.	N E B.	P H A.	P E A.	P H B.	P E B.	PP H A.	PP E A.	PP H B.	PP E B.
½	ccc	.....	.....	.....	.....	.....	ccc	ccc	.....	.....	.....	.....
1	ncn	.....	.....	.....	.....	.....	ncc	cnc	.....	.....	.....	ccc
2	cpc	ccc	ccc	ccc	ccc	cc	ccn	ncn	.....	.....	cc	ncc
4	n	ccc	cpc	cnn	ncn	ccc	n	cnn	.....	.....	.....	ccn
8	.....	ppp	n	p	.....	ccn	.....	.....	.....	.....	ccc	n
16	.....	.....	.....	.....	.....	nnn	.....	.....	.....	.....	ccc	.....
24	n	p	n	n	.....	n	.....	.....	.....	.....	cnn	.....
48	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
72	.....	.....	.....	.....	.....	.....	.....	.....	ccc	ccc	.....	.....

GRADE II.

½	ccc	.....	ccc	.....	.....	.....	.....	.....	.....	.....	ccc	ccc
1	ppc	.....	nnn	ccc	.....	.....	ccc	ccc	.....	.....	cnc	ccn
2	ncc	ccc	nnn	cnn	ccc	ccc	cn	ncc	.....	.....	ccn	ncn
4	n	ncc	n	n	cnc	ccn	n	n	.....	.....	p	.....
8	.....	.....	.....	.....	ccn	cn	.....	.....	.....	.....	n	.....
16	.....	.....	.....	.....	ccn	n	.....	.....	.....	.....	.....	.....
24	n	n	n	n	.....	.....	.....	.....	.....	.....	.....	.....
48	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
72	.....	.....	.....	.....	.....	.....	.....	.....	ccc	ccc	.....	.....

GRADE III.

½	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	ccc	.....
2	.....	.....	.....	.....	ccc	.....	ccc	.....	.....	.....	ppc	.....
4	.....	.....	ccc	.....	pcp	.....	nnn	.....	.....	.....	.....	.....
8	.....	.....	npc	.....	ncp	.....	pn	.....	.....	.....	cpn	.....
16	.....	.....	ncn	.....	nnc	.....	npp	ccc	.....	.....	ccn	.....
24	ccc	c	cpc	c	nn	.....	cp	cn	.....	.....	pp	ccc
48	cn	.....	np	ccc	nn	.....	.....	.....	.....	.....	.....	ccc
72	cnn	ccc	nnc	ccp	cpn	ccc	nnn	n	ccc	ccc	ncp	pcc

The maximum hours of immersion resisted by the five explosives under the various conditions are as follows:

TABLE 7.—*Hours of immersion resisted by five explosives.*

Kind of cartridge.	40 per cent straight nitroglycerin dynamite.		40 per cent ammonia dynamite.		TNT.					
					Grade I.		Grade II.		Grade III.	
	A	B	A	B	A	B	A	B	A	B
As received	24	48	48	24						
N H					½	2	½	½	24	4
N E					4	2	2	1	72	48
P H					2	½	2	1	2	2
P E					4	½	2	1	72	16
PP H					72	16	72	½	72	1
PP E					72	1	72	½	72	48

CONCLUSIONS FROM EXPERIMENTS.

When both ends of cartridges of all grades of TNT are redipped and not punctured, they withstand water fully as well as the dynamites when tested as received. This shows the efficacy of this type of cartridge and is independent of the nature of the explosive within the cartridge.

Grade III TNT in cartridges resists water for 1 to 72 hours or more, the time depending upon the density at which packed and the nature of the cartridge. In all tests with Grade III TNT, the cartridges that were packed easily withstood the water better than those that were packed hard. Grade III has very much better water-resisting properties than either of the other grades of TNT, especially when packed easily, and compares very favorably with the dynamites tested.

Of the three grades of TNT, the only one recommended for use in wet holes in cartridge form is Grade III. The others may be used for wet work if packed in completely redipped paraffined cartridges, provided they can be charged without breaking the cartridges.

EXPERIMENTS AT UNIVERSITY OF WISCONSIN.

This problem was independently attacked at the University of Wisconsin in the following manner: $2\frac{3}{4}$ ounces of TNT was carefully weighed and placed in bottles and various percentages of water were added. Each bottle was then thoroughly shaken to mix the water with the TNT. After standing a short time, each charge in its bottle was primed with a No. 6 or No. 8 detonator and fired, giving the results shown in Table 8.

TABLE 8.—*Water resistance of TNT (temperature, 80° F.).*

Bottle No.	Water added.	Strength of detonator.	Result.
	Per cent.		
1	5	No. 8	Detonated.
2	5	No. 6	Do.
3	7	No. 8	Do.
4	7	No. 6	Detonated (incomplete).
5	10	No. 8	Detonated.
6	10	No. 6	No detonation or very incomplete.
7	15	No. 8	No detonation.
8	15	No. 6	Do.

In addition several cartridges of TNT, were placed in a creek near by and left in the water for 48 hours. These cartridges were all well paraffined. No difference could be noted in the detonation or field results obtained with these cartridges before and after soaking. Similar results were obtained with cartridges of "20 per cent" ammonia dynamite. Apparently the water resistance under these conditions depended on the paraffin on the cartridges. Cartridges with a hole punched in the wrappers were not, after 72 hours exposure in the water, detonated by No. 8 detonators.

DESENSITIZING TNT

Recent experiments at the explosives experiment station of the Bureau of Mines by Edmund Stein have determined the minimum percentage of certain desensitizing materials, when thoroughly and intimately mixed, required to prevent detonation by a No. 8 electric detonator or TNT booster and the propagation of combustion through TNT, Grade I, to be as follows:

TABLE 9.—*Minimum percentage of material required to desensitize TNT, Grade I.*

Material.	To prevent detonation.	To prevent continuous combustion.
Water	14	2
Kieselguhr	16	52
Sodium chloride	96	.....

EXPERIMENTS IN WISCONSIN ON EFFECT OF SOIL MOISTURE ON EFFICIENCY OF EXPLOSIVES.

In its field experiments on the use of explosives in land clearing, the college of agriculture of the University of Wisconsin has studied the effect of soil moisture on the economic efficiency in stump blasting. Dynamite was the explosive used in this study, but the variations in soil conditions under which the tests were made would have been the same for any other explosive, and it is probable that although the variation in soil-moisture content might modify the efficiency of another explosive to a different degree, the variations in efficiency would be in the same directions and of similar magnitudes. There-

fore, a brief report on these experiments by the college of agriculture, February, 1920, is presented here as a guide in using TNT.

EFFECT OF SOIL MOISTURE ON EFFICIENCY OF DYNAMITE IN STUMP REMOVAL.

The results of the experiments showed that it cost about 50 per cent more to remove stumps during the dry part of the summer than in the late fall when the soil was wet, other conditions being the same.

The plots selected originally were timbered with mixed hardwood timber which had been cut six years. In each plot the average size of the stumps was 15 inches. The soil was the Kennan silt loam at North Crandon, Forest County. The land was level and well drained.

All of the stumps were completely blasted for hand piling. Piling labor cost at the rate of 10.5 cents per stump. Where an additional charge of dynamite was required to complete the removal, it is included in the costs in the table. "Twenty per cent" dynamite was figured at 16 cents a pound and electric caps at 8 cents each. Labor was fixed at 25 cents an hour.

TABLE 10.—*Comparative cost of stump removal by dynamite in dry and wet soils.*

Item.	Dry (August).	Wet (October).
Number of stumps blasted	75	102
Dynamite used.....pounds	133.75	99.5
Number of detonators	123	112
Hours of labor	39	46.5
Cost per stump:	*Cents.*	*Cents.*
Dynamite	28.53	16.6
Detonator	13.12	8.78
Labor	13	11.4
Total	54.65	36.78

The work was done in 1917 by the land-clearing crew of the college of agriculture. During July but little rain had fallen, so that the soil was very dry for the August stumping. From August 7 to October the rainfall amounted to 8.03 inches. Much of this fell shortly before October 26, so that for the late fall stumping the soil was reasonably wet.

There was a saving in dynamite, detonators, and labor under the wet conditions. The moisture facilitated the making of the holes for placing the dynamite.

The results of this experiment are definite and conclusive. The advantage of blasting in the spring, or at some other wet period of the year, may amount to $20 an acre where there are 100 stumps or more to the acre.

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